FIELD DEMONSTRATION OF ENHANCED SORBENT INJECTION FOR MERCURY CONTROL

QUARTERLY TECHNICAL PROGRESS REPORT

Reporting Period: January 1 – March 31, 2005

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Disclaimer

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AC	activated carbon
BOP	balance of plant
CMM	Continuous mercury measurement
DOE	U.S. Department of Energy
EERC	Energy and Environmental Research Center
ESP	electrostatic precipitator
NETL	National Energy Technology Laboratory
NDIC	North Dakota Industrial Commission
PRB	Powder River Basin
SCA	specific collection area

Executive Summary

ALSTOM Power Inc, Power Plant Laboratories (ALSTOM-PPL) has been awarded a consortium-based, DOE-NETL program to demonstrate Mer-Cure™ technology, ALSTOM-PPL's novel and oxidation-based mercury control technology in coal-fired boilers. In the program, ALSTOM-PPL teams up with the University of North Dakota – Energy and Environmental Research Center (EERC), PacifiCorp, Basin Electric Power Cooperative (Basin Electric), Reliant Energy, North Dakota Industrial Commission (NDIC), and Minnkota Power.

The full-scale demonstration program consists of three seven-week long test campaigns in three independent host sites firing a wide range of coal ranks. These host sites include PacifiCorp's Dave Johnston Station burning a Powder River Basin (PRB) coal, Basin Electric's 220-MW_e Leland Olds Unit 1 burning a North Dakota lignite and its blend with a PRB, and Reliant Energy's 170-MW_e Portland Unit 1 burning an Eastern bituminous coal. These boilers are all equipped with an electrostatic precipitator (ESP).

In Mer-Cure™ technology, a small amount of sorbent (Mer-Clean™) is injected into a flue gas stream environment where the gaseous elemental mercury oxidation and removal is favorable. The sorbents are prepared with chemical additives that promote oxidation and capture of elemental mercury. The Mer-Cure™ mercury control technology offers a great opportunity for utility companies to control mercury in the most cost-effective manner while minimizing any balance-of-plant impact.

ALSTOM-PPL has made a significant progress during the reporting period. The accomplishments during the period are summarized below:

- Signed Host Site Agreement with PacifiCorp;
- Signed Subcontract Agreements with host sites;
- Had an overall project kick-off meeting at DOE/NETL site;
- Had site kick-off meetings at Reliant Energy and Basin Electric and collected site information;
- Performed baseline mercury level measurements and collected site information for PacifiCorp's Dave Johnston Station;
- Selected Dave Johnston Unit 3 for the first demonstration based on the measurement data;
- Completed design and engineering of Mer-Cure™ system;
- Ordered major components for Mer-Cure™ system; and
- Fabrication of Mer-Cure™ system is in progress.

INTRODUCTION

The overall objective of the DOE/NETL-sponsored project is to perform full-scale demonstration of Mer-Cure™ technology in three coal-fired boilers burning coals of various ranks. These host sites include PacifiCorp's Dave Johnston Station burning a PRB coal, Basin Electric's 220-MW_e Leland Olds Unit 1 burning a North Dakota lignite, and Reliant Energy's 170-MW_e Portland Unit 1 burning an Eastern bituminous coal. These boilers are all equipped with an ESP (Table 1).

In the program, ALSTOM-PPL will demonstrate that greater than 70% of gaseous mercury in the flue gas can be captured by injection of enhanced sorbent at a feed rate significantly lower than required by standard activated carbon. ALSTOM-PPL will also collect performance data that can be used to accelerate commercialization of our mercury control technology.

Mer-Cure™ technology applied to coal-fired power generation has the potential to be a cost-effective mercury control technology for the entire range of coals (bituminous, sub-bituminous, and lignite) and, in particular, the more challenging coals (for example, PRB and lignite coal). This control technology has low-capital costs (less than \$5/kW_e). It also requires a very small amount of additives for treatment, which results in low operating costs (0.5-0.75 mills/kWh) and minimal balance-of-plant (BOP) impact. As the technology is based on oxidation and adsorption of mercury, it is also applicable to all air pollution control configurations including wet scrubber and spray dryer-ESP/baghouse units. The main focus of the project, however, is coal-fired boilers with a cold-side ESP as the particulate control device, which represents 70% of the installed base in the United States.

The test program includes installation of equipment for the mercury control system, its operation under various firing conditions and measurement of elemental and oxidized mercury concentrations in the flue gas. The testing will include a one-week baseline mercury measurement and two weeks of parametric testing, followed by a four-week long-term testing. During the two-week parametric testing, the ALSTOM mercury control system will be operated with sorbents of several formulations at different sorbent injection rates to determine mercury oxidation and removal efficiencies. The optimum sorbent formulation and injection rate will be selected for the four-week testing to evaluate its long-term performance.

The EERC will participate in the proposed program by providing mercury measurement expertise. Continuous mercury measurement (CMM) will be carried out throughout the test period by installing CMM monitors before the injection location and after the ESP to provide both elemental and oxidized mercury concentrations in the stack gas. Ontario Hydro method will also be employed for some of the key test conditions to verify CMM data, to obtain mercury concentration and speciation measurements at ESP, and to ensure QA and QC of the measurements.

ALSTOM-PPL believes that our mercury control technology offers a great opportunity for utility companies to control mercury in the most cost-effective manner while minimizing any balance-of-plant impact. ALSTOM also believes that the DOE-sponsored full-scale demonstration of the technology will accelerate our commercialization effort of Mer-Cure™

technology.

Table 1. Host site, coal and emission data for the field demonstration program (as proposed in the original proposal submitted to DOE/NETL)

	PacifiCorp	Basin Electric		Reliant Energy
Unit	Dave Johnston 1	Leland Olds 1		Portland 1
Capacity (MW_e Gross)	110	220		172
Operation	Base-loaded	Base-loaded		Cycling
NO_x and SO_2 control	No low-NO_x Low sulfur coal	No low NO_x Low sulfur coal		Low-NO_x - LNCFS No sulfur control
Air Heater	Ljungstrom	Ljungstrom + Tubular		Ljungstrom
Particulate control (SCA in ft^2/kacfm)	CS-ESP (706)	CS-ESP (320)		CS-ESP (284)
Ash utilization	Disposal	Disposal		Disposal
Coal	PRB	ND lignite; ND lignite-PRB blend		Bailey mine Pittsburgh seam coal
Higher Heating Value As-received(Btu/lb)	8,608	Lignite 6617	PRB 8,071	12,800 – 13,100
S in coal (%)	0.43	0.63	0.43	2-2.5%
Ash %	5.31	9.86	5.22	6-8%
Cl in coal (ppmwd)-dry	92 - 95			~1,500
	PRB coal data	Lignite coal data		Bituminous coal data
Hg in coal (ppmwd)-dry	0.071-0.083	0.057-0.099		0.1-0.16
As-fired Hg level from Coal ($\mu g/Nm^3$)	7-9	6-10		10-16
Inlet Hg* ($\mu g/Nm^3$)	T-10.7; PM-9.1; Ox-0.2; El-1.4*	T-7.9; PM-2.0; Ox-0.1; El-5.8- March '03		T-9.1; PM-0.9; Ox-7.4; El-0.8^{+}
Uncontrolled Hg Emission* Stack (Hg^T, Hg^p, Hg^{ox}, Hg^{el}) ($\mu g/Nm^3$)	T-2.7; PM < 0.13; Ox-1.2; El-1.4*	T-7.8; PM-0.0; Ox-1.4; El-6.4- March '03		T-7.5; PM-0.0003; Ox-5.2; El-2.3^{+} after ESP, before scrubber
Removal Efficiency (ICR data)	8.5 – 12%	12-25%		36% for bituminous coals with CS-ESP
Carbon-in-ash	0.5-1.6%	< 0.2%		10-12%
Flue gas temp (ESP Inlet)	276^{o}F	375^{o}F		277^{o}F – full load

*Unit 2 data. Unit 2 similar to Unit 1 & fires the same coal
$^{+}$Data from 150 MWe AES-Cayuga (CE-LNCFS III with an ESP/scrubber) burning similar Pittsburgh seam coal with 2.3% S, 0.09% Cl and 0.1 ppmd Hg

Since submission of the proposal, host sites have rescheduled their outages as listed in Table 2. Since their outages all occur in the months of March through June 2005, any preparation for plant modifications related to the test campaigns for all three sites have to be completed before the end of March. These include site-specific design of the system such as lance design, and identification of injection locations and sampling locations. In the reported performance period, therefore, a great deal of design work has been carried out for all three sites. This will continue into the next performance period.

Table 2. Scheduled outages of the three host sites

Host sites	Scheduled outage	Demo period
PacifiCorp Dave Johnston 1	Apr 2 – Apr 9, 2005	mid June – mid Aug, 2005
or PacifiCorp Dave Johnston 3	Apr 30 – May 31, 2005	
Basin Electric Leland Olds 1	June, 2005	early Sept – early Nov, 2005
Reliant Portland 1	Mar 26 – May 2, 2005	mid Mar – mid May, 2006

EXPERIMENTAL

The four major tasks being performed for the on-going demonstration project are:

Task 1A. Design, Engineering and Fabrication of the Mer-Cure™ System
Task 2A. Field Demonstration
Task 3. Technology Transfer
Task 4. Program Management and Reporting.

During the performance period, project activities were mainly for Task 1A and 4. Details of the project activities are described in this section.

Task 1A. Design, Engineering and Fabrication of Mer-Cure™ System

Baseline mercury measurement at PacifiCorp's Dave Johnston Units:

In preparation for the first campaign of the program, ALSTOM-PPL has performed initial measurements of uncontrolled mercury level from PacifiCorp's Dave Johnston Units 1 and 3 in early January 2005. Both units are base-loaded units with electrostatic precipitators. They have two Ljungstrom™ air heaters. Dave Johnston Unit 1 burns Cordero Rojo coal while Unit 3 burns Wyodak coal. Both coals are, however, PRB coals with low chlorine content.

Sampling was carried out at the stacks of Unit 1 and 3. The temperature of flue gas at the sampling location was approximately 290 - 320°F. The baseline mercury measurement was carried out using Frontier GeoSciences' FAMS (Flue gas Adsorbent Mercury Speciation) method. The FAMS method relies on sequential selective capture to separate and quantify three mercury species: particulate mercury, Hg (p), gaseous oxidized mercury, Hg (II), and gaseous elemental mercury, Hg (0). A known volume of flue gas is pulled through the FAMS sorbent train using standard sampling equipment including a quartz probe liner, heated probe, silica-gel water trap, mass flow meter and pump. The Hg (p) is captured on a quartz-fiber filter with the gas phase Hg (II) and Hg (0) separated selectively on specialized solid sorbent traps. The temperature of the FAMS sorbent train is kept at 95 ± 5 °C during sampling to avoid water condensation in the trap. The adsorbed Hg (0) on the Hg (0) solid sorbent section of the speciation trap and the Hg (p) on the quartz filter is leached of collected Hg in a clean lab using hot-refluxing, oxidizing acid, then reduced with a reducing agent solution. The adsorbed Hg (II) on the Hg (II) solid sorbent section of the speciation trap is dissolved in a reduction solution. Aliquots of all three Hg species digests are then analyzed using cold vapor atomic fluorescence spectroscopy (CVAFS).

The measured mercury levels along with coal data are listed in Table 3. The total mercury level from the Unit 1 was between 1.61 and 1.93 $\mu g/m^3$ whereas that from the Unit 3 was between 5.55 and 8.71 $\mu g/m^3$. Despite fuels for both units being PRB coals, the Unit 1 had significantly lower mercury emissions level than the Unit 3, indicating significant inherent removal takes place in Unit 1. Also about 60% of the total mercury emitted was in oxidized form for both Units. Some of the reasons for such a low level for Unit 1 may include

(i) boiler operation – Unit 1 runs at a higher CO emission level (approximately 500 ppm) than Unit 3 (approximately 90 ppm), suggesting less efficient combustion, and, therefore, higher carbon-in-ash;
(ii) chlorine content of coal – the coal of Unit 1 (Cordero Rojo) has higher chlorine

levels than that of Unit 3 (Wyodak);

(iii) flue gas temperature at the ESP inlet – Unit 1 has about 280°F whereas the Unit 3 has about 320°F.

The three factors mentioned are likely to have contributed to higher native capture and lower stack mercury emissions level in Unit 1 than in Unit 3. The mercury level of 1.6 to 1.9 $\mu g/m^3$ is low enough to cause significant mercury measurement errors, and led to re-evaluation of the test program at Dave Johnston Unit 1. After discussions with PacifiCorp and DOE/NETL, a decision has been made to carry out the first demonstration at Unit 3, rather than at Unit 1.

Table 3. Comparison between PacifiCorp's Dave Johnston Unit 1 and Unit 3

Unit	Dave Johnston 1	Dave Johnston 3
Capacity (MW_e Net)	110	220
Operation	Base-loaded	Base-loaded
NO_x and SO_2 control	No low-NO_x Low sulfur coal	No low-NO_x Low sulfur coal
Air Heater	Two Ljungstrom™ air heaters	Two Ljungstrom™ air heaters
Particulate control (SCA in ft^2/kacfm)	CS-ESP (706)	CS-ESP (629)
Ash utilization	Disposal	Sold for mine reclamation
Coal	Cordero (PRB)	Wyodak (PRB)
Proximate analysis		
Moisture	29.79	30.73
Ash	5.49	7
Volatile m. + fixed carbon	64.72	62.27
HHV (Btu/lb)	8,421	8060
Ultimate analysis (dry basis)		
Hydrogen	4.8%	4.92%
Carbon	68.46	67.75
Sulfur	0.43	0.94
Nitrogen	1.07	0.94
Oxygen	17.77	15.44
Ash	7.49	10.09
Cl in coal (ppmwd)-dry	101-327	<50
Hg in coal (ppmwd)-dry	0.038-0.094	0.071
Particulate Hg at stack ($\mu g/m^3$)	0.12 – 0.37	0.01 – 0.04
Elemental Hg at stack	0.4 – 0.6	2.4 – 4.35
Oxidized Hg at stack	0.93 – 1.21	3.1 – 4.35
Total Hg at stack	1.61 – 1.93	5.55 – 8.71

Design and Fabrication of Mobile Mer-Cure™ System

ALSTOM-PPL has started designing the system architecture of Mer-Cure™ system. In the proposal, ALSTOM-PPL was planning on leasing major components of the Mer-Cure™ system for each of the three test campaigns of the field demonstration program. In re-evaluating the associated costs (i.e., material and labor for installation and removal) after the award, ALSTOM-PPL has reached a conclusion that purchase of major components and assembly of a pre-assembled, mobile system for testing in three sites would simplify the preparation, installation, testing, and system removal, ensuring smoother execution of the program. This design approach has been communicated with DOE program managers for approval and adopted for the demonstration program.

During the performance period, ALSTOM-PPL has ordered major pieces of the Mer-Cure™ system and will be assembling a mobile system as soon as they arrive at our site. The mobile Mer-Cure™ system design is composed of three components mounted on a 40-foot trailer: a sorbent storage system, a sorbent processing/delivery system, and a sorbent distribution system.

The sorbent storage system ordered for the testing is a portable solid storage silo that comes in two pieces (each piece is 8 ft high), can be easily assembled, and requires a relatively small footprint. The sorbent storage system, when assembled, is capable of loading powdered material of up to three 900-lb super-sack bags at the same time and will allow uninterrupted operation for 24 hours at a typical injection rate. Due to height limitations of the trailer during transportation, the storage system will be delivered unassembled. The top piece of the two-piece storage system will be attached to the base piece permanently mounted on the trailer at the test site before testing.

The sorbent processing/delivery system is a variable screw feeder for metering the sorbent and an eductor for its pneumatic transport to a processor, a processor that de-agglomerates sorbent particles, and a system for dry, compressed air for pneumatic transport. This system will be mounted next to the storage system and completely connected to the other subsystems.

The sorbent distribution system is a flexible hose and interconnecting pipes, distribution manifolds and injection lances. The injection lances are a number of 1 ¼-inch pipe sections with multiple nozzles for even distribution throughout the duct cross-section at the injection location. The injection lances will be designed based on computational fluid dynamics (CFD) studies.

In preparation for the design of the site-specific portion of the Mer-Cure™ system, site visits were made to all three sites. During the visit, more detailed information was collected such as that on the injection location (e.g., duct dimensions, turning vane arrangement), workspace, sampling port locations, trailer placement, equipment placement and the availability of utilities at work locations.

Uniform distribution of sorbents into the flue gas stream is very important for good contact between the sorbents and the mercury in the flue gas stream. During the visit, ALSTOM-PPL collected boiler design data to complete flow modeling calculations. These flow-modeling studies will allow specific design and better determination of the location and the number of injection lances.

Computational Fluid Dynamics Study for Injection Lance System Design

Figure 1 shows the injection location of the Dave Johnston Unit 3. The injection lance location and design (e.g., nozzle arrangement) are closely related to the degree of dispersion of mercury sorbent into the flue gas stream. In-flight capture of mercury by fine sorbent particles is enhanced as their dispersion becomes more uniform across the duct dimension. For a design of an injection lance system with enhanced in-flight capture, ALSTOM-PPL has been conducting flow study for all of the three boilers using Fluent CFD package.

Figure 1. Injection location of Dave Johnston Unit 3

Figure 2 shows some of the results from the CFD study for the back-pass of Dave Johnston Unit 3 in the region of injection. The unit has two horizontal ducts out of the economizer section as shown in the x-y plane in Figure 2. The dimensions of these ducts expand in horizontal direction while they slightly reduce in vertical direction. The flow profile in the x-y plane (the horizontal plane along the flow direction) from the CFD study suggests that the flue gas flow out of the economizer section is concentrated mostly in the center of the duct. On the other hand, the flow profile in the x-z plane (the vertical plane along the flow direction) shows relatively even distribution in the vertical directions in the duct.

Based on the flow distributions, a lance system is being designed for PacifiCorp's Dave Johnston Unit 3. Flow studies are being carried out for the other two test sites before outages. Results for the two sites will be presented in the next reporting period.

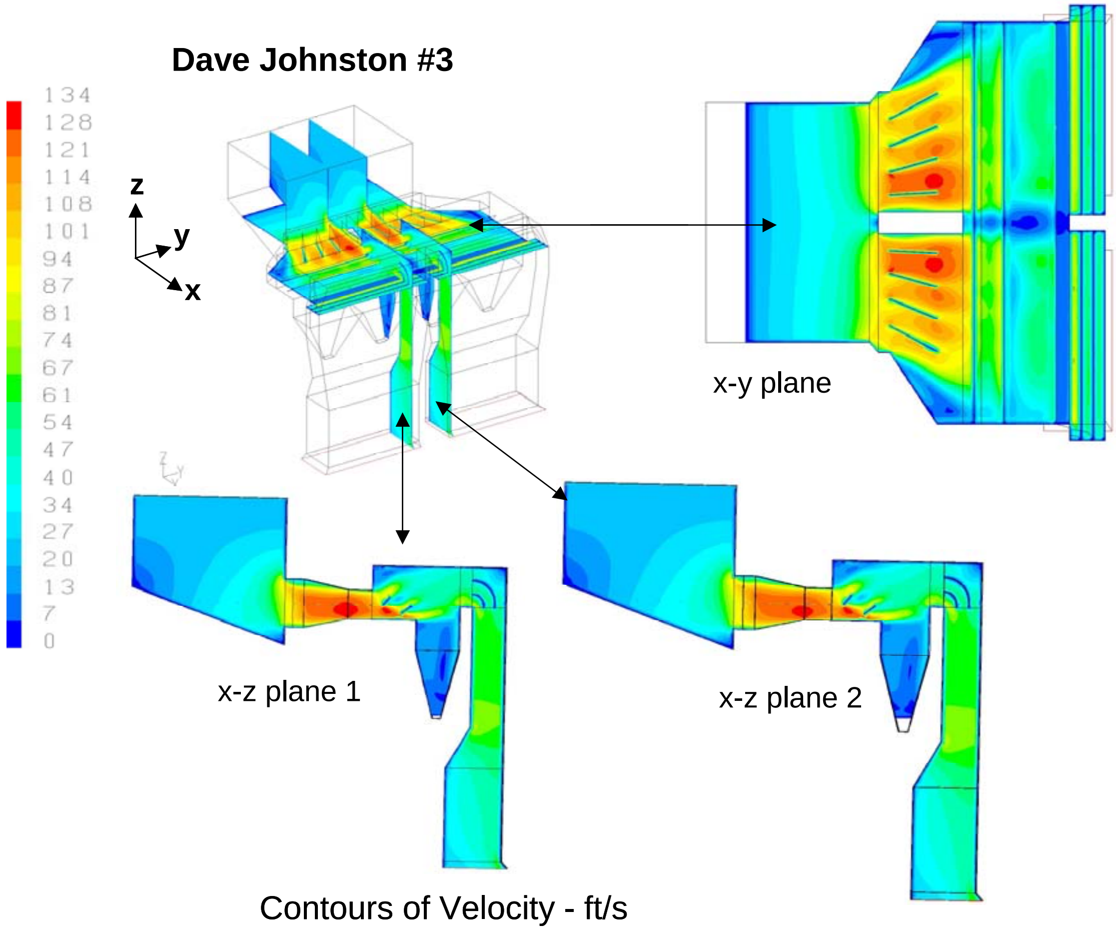

Figure 2. Flow distribution contours at the back-pass of Dave Johnston Unit No. 3

Task 2A. Field Demonstration for PacifiCorp Campaign

No activities for this task during the reporting period.

Task 3. Technology Transfer

No activities for the task during the reporting period.

Task 4. Project Management and Reporting

During the reporting period, ALSTOM-PPL has had a project kick-off meeting with DOE and other team members at the DOE/NETL site. We also had a site kick-off meeting at Reliant Energy's Portland site and Basin Electric's Leland Olds site. We have executed a Host Site Agreement with PacifiCorp, and are in the process of completing Host Site Agreement with Reliant Energy. (The Basin Electric Host Site Agreement had already been executed in the last quarter.)

RESULTS AND DISCUSSION

No testing was performed during the reporting period.

MILESTONES AND SCHEDULE

Table 4. Schedule

ID	Task Name
1	**Design, Engineering, and Fabrication, Dave Johnston Unit**
2	Design and Engineering of System Architecture
3	Component Fabrication and Testing
4	Assembly and Shipping
5	**Field Demonstration, Dave Johnston Unit 1**
6	Project Kickoff Meeting, Environmental/Regulatory Approvals
7	Installation, Checkout, and Commissioning
8	System Setup - Milestone 1
9	Testing
10	Removal
11	Data Analysis and Site Report
12	Site Report - Milestone 2
13	**Design, Engineering, and Fabrication, Leland Olds Unit 1**
14	Design and Engineering of System Architecture
15	Component Fabrication and Testing
16	Assembly and Shipping
17	**Field Demonstration, Leland Olds Unit 1**
18	Project Kickoff Meeting, Environmental/Regulatory Approvals
19	Installation, Checkout, and Commissioning
20	System Setup - Milestone 3
21	Testing
22	Removal
23	Data Analysis and Site Report
24	Site Report - Milestone 4
25	**Design, Engineering, and Fabrication, Portland Unit 1**
26	Design and Engineering of System Architecture
27	Component Fabrication and Testing
28	Assembly and Shipping
29	**Field Demonstration, Portland Unit 1**
30	Project Kickoff Meeting, Environmental/Regulatory Approvals
31	Installation, Checkout, and Commissioning
32	System Setup - Milestone 5
33	Testing
34	Removal
35	Data Analysis and Site Report
36	Site Report - Milestone 6
37	**Technology Transfer**
38	Technology transfer
39	**Program Management and Reporting**
40	**Program Management**
432	**Reporting - As Needed**
463	Final Report
464	Final Report - Milestone 7

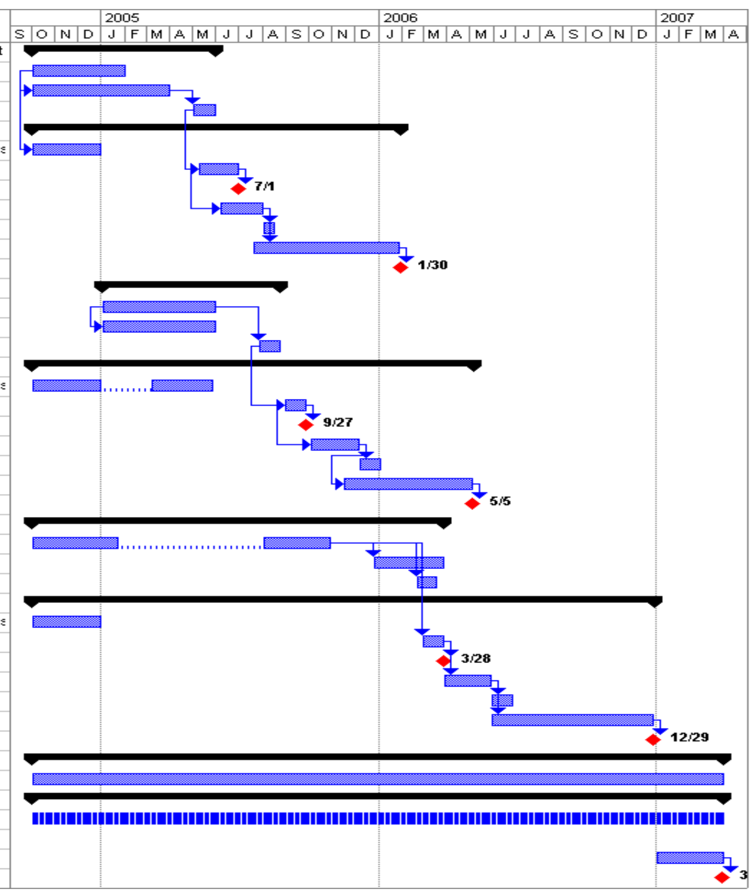

Table 5. Milestone and Deliverables

Milestone/ Deliverable	Original	Revised	Actual
1. System setup – Dave Johnston (PacifiCorp)	7/1/05		
2. Site Report – Dave Johnston (PacifiCorp)	1/30/06		
3. System setup – Leland Olds (Basin Electric)	9/27/05		
4. Site Report – Leland Olds (Basin Electric)	5/5/06		
5. System setup – Portland (Reliant)	3/28/06		
6. Site Report – Portland (Reliant)	12/29/06		
7. Final Report	3/30/07		

BUDGETS

The overall budget for this project is $ 4,980,821. The funding release amount including costshare for the performance period was $400,000. The actual amount spent to date is $315,075. The program is on schedule and on budget.